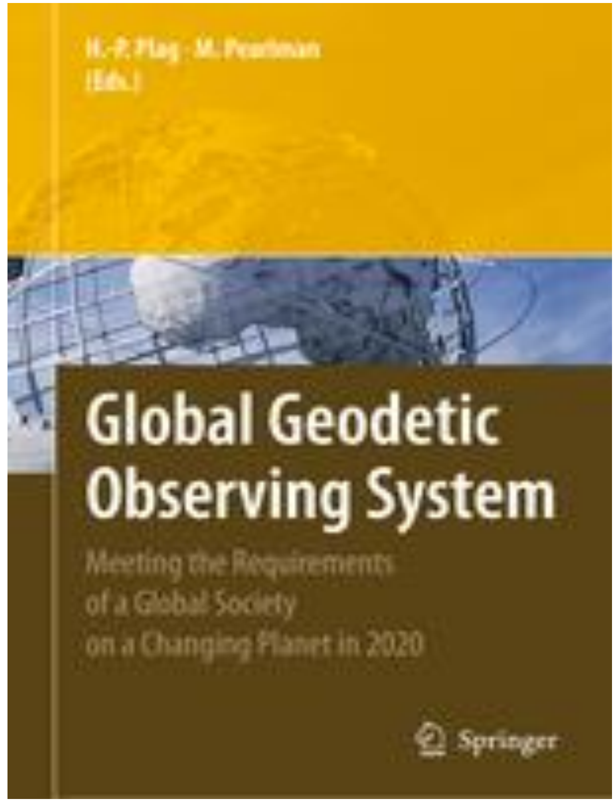
The Promise and Challenges of Accurate Low Latency GNSS for Environmental Monitoring and Response

John LaBrecque
Geohazards Focus Area
Global Geodetic Observing System
Center for Space Research
University of Texas, Austin
Email: jlabrecq@mac.com

With special appreciation to NASA SCAN for support

The Promise of GGOS

Politics



Habits

Technology

Performance

And Our Challenges

Politics

Habits

Technology

Performance

The Global Geodetic Observing System

International Terrestrial Reference Frame (ITRF)

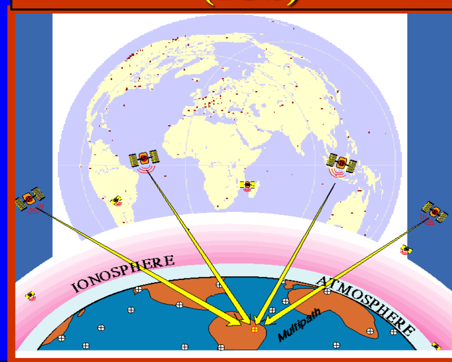
International Earth Rotation Service (IERS)

Precision GPS Orbits and Clocks, Earth Rotation Parameters, Station Positions

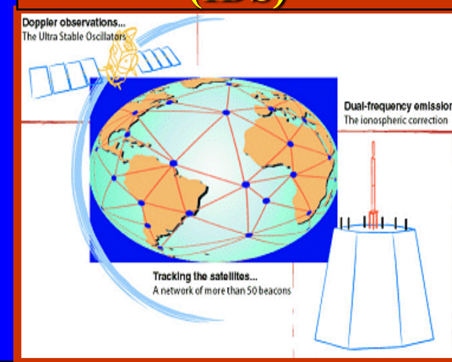
Very Long Baseline Interferometry (IVS)

Satellite Laser Ranging (ILRS)

Global Navigation Satellite Systems (IGS)

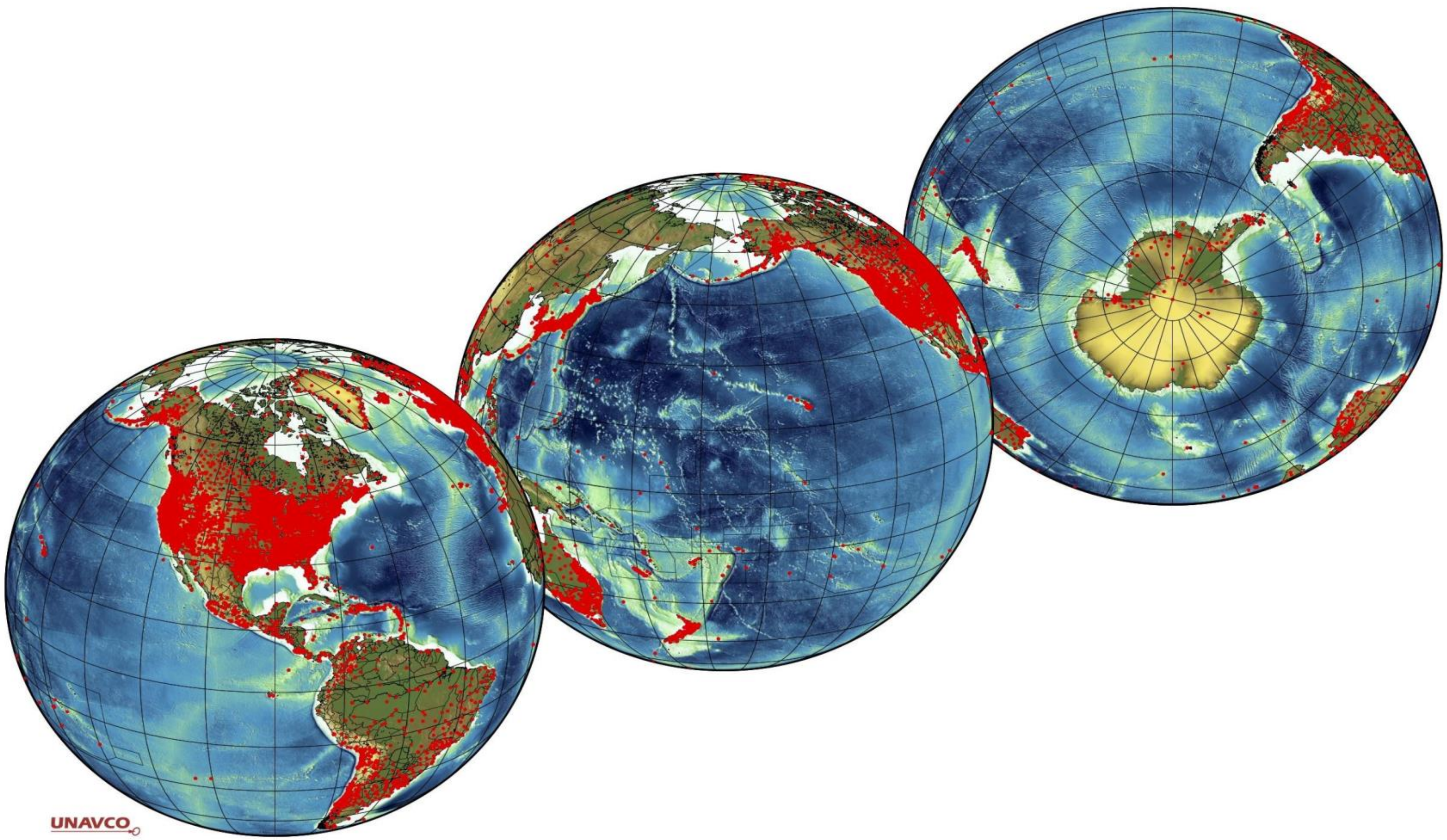


Doppler Orbit Determination and Radiopositioning Integrated on Satellite (IDS)



GNSS utilization is nearly universal

14,700 Known and Publically Accessible Continuous GNSS sites



luced by UNAVCO/Mencin 2015

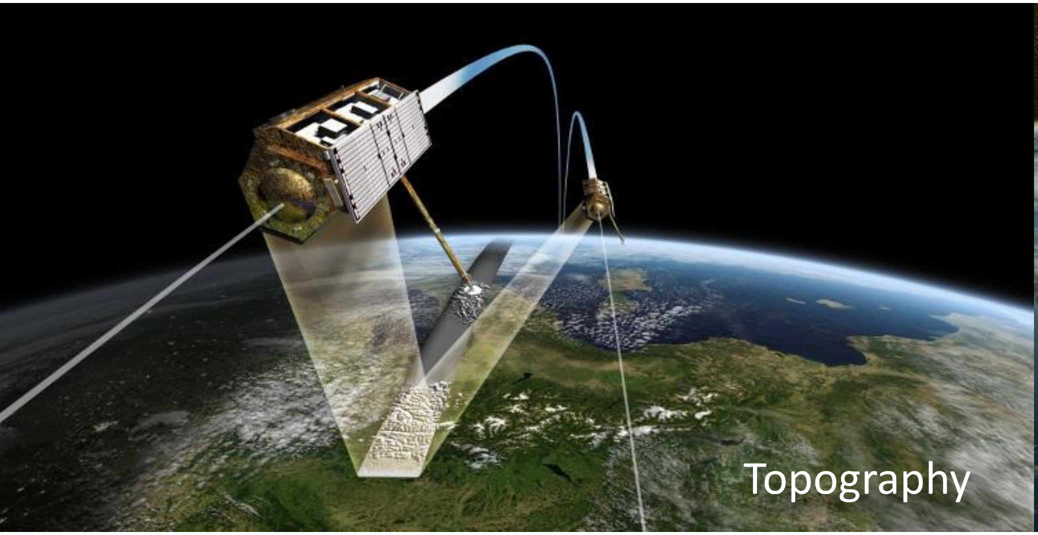
Global Navigation Satellite Systems (GNSS) provide essential inputs to the ITRF

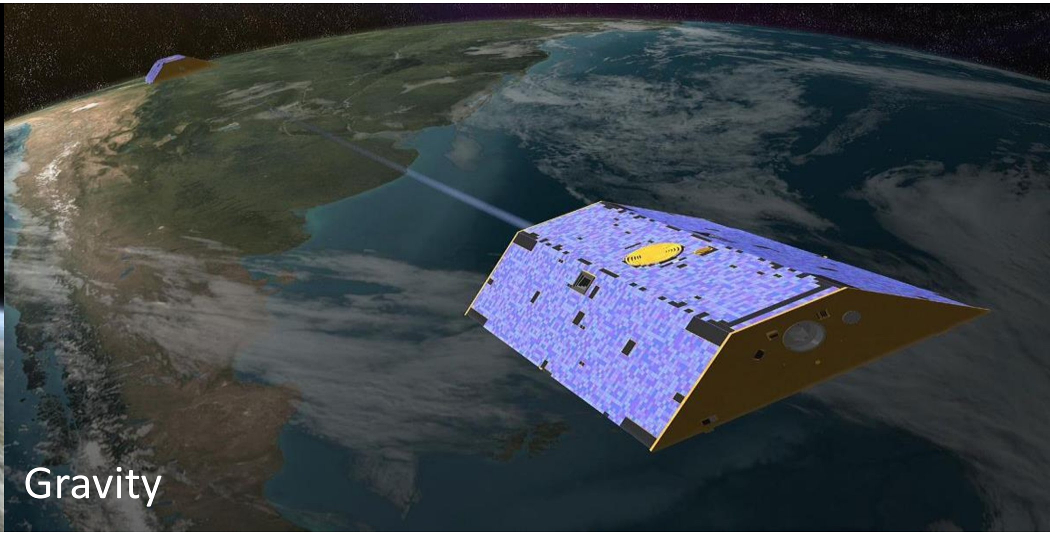
(e.g. time transfer, polar motion, relative sensor positioning, tectonic motion……)

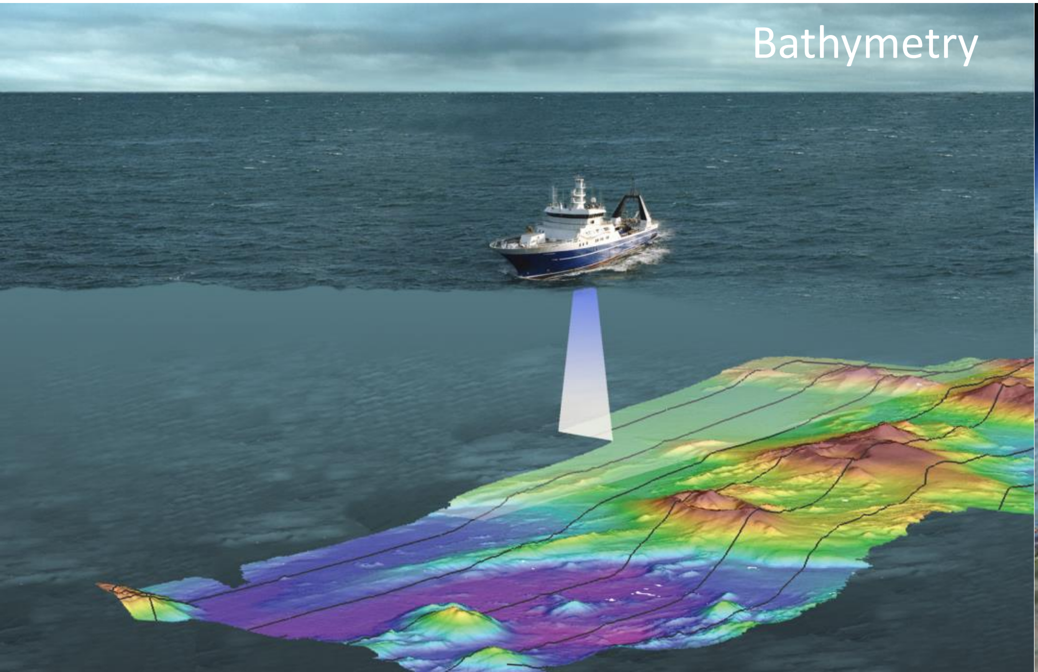
and

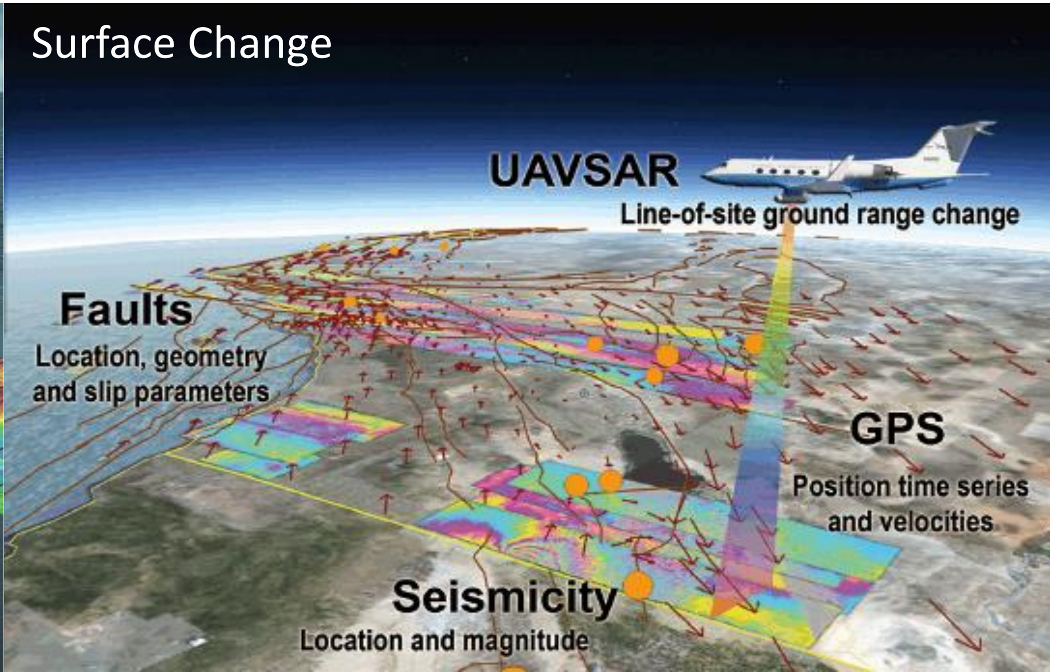
GNSS are the means by which the world utilizes the ITRF

GNSS provide accurate high rate positioning within the ITRF

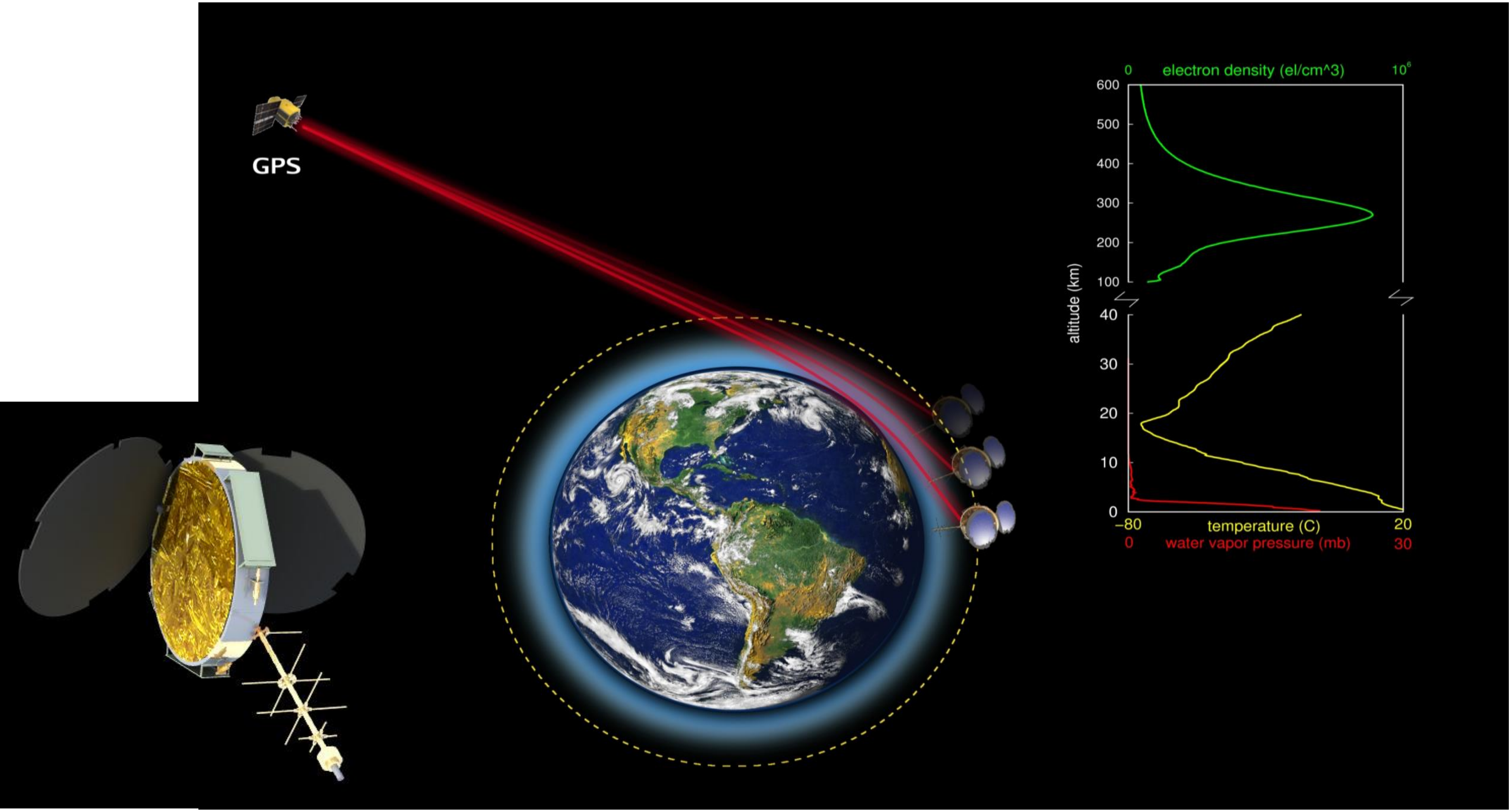








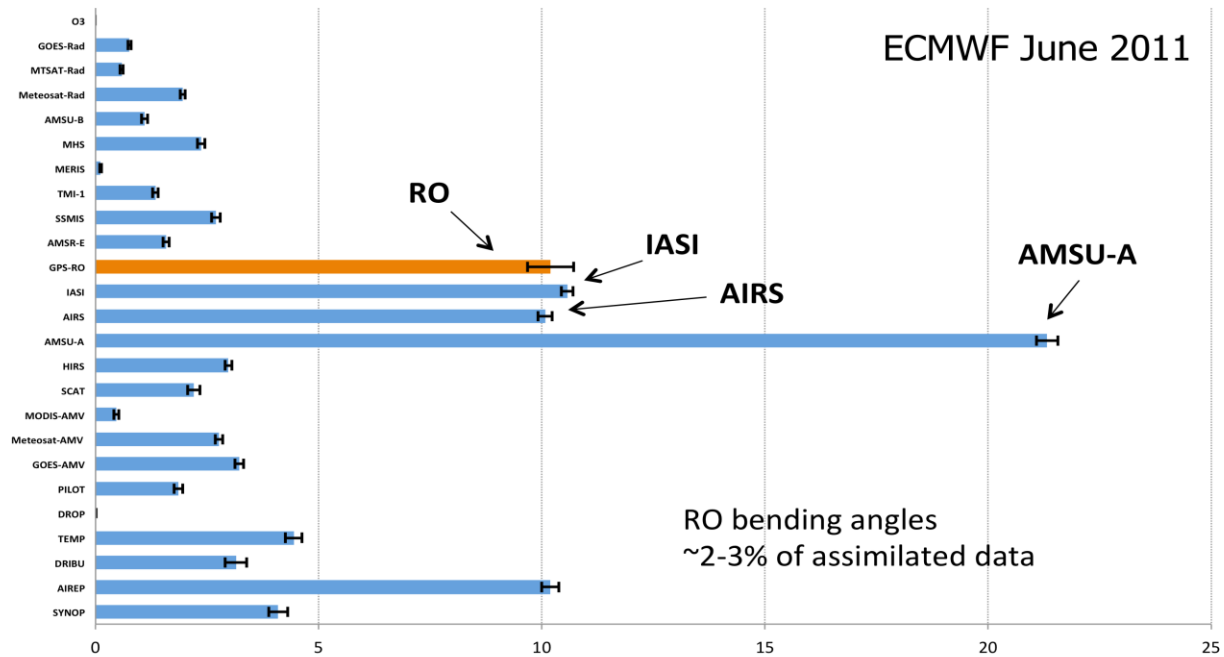
Atmospheric and Ionospheric Dynamics



GNSS occultation samples the occulting signal at up to 100 samples/sec
Data must be downloaded processed rapidly to meet 3 hr weather model schedules
Ground networks provide satellite navigation, navigation message and system biases

The current importance of GPS Occultation to ECMWF Weather Forecasting :

Reduction in Forecast Error



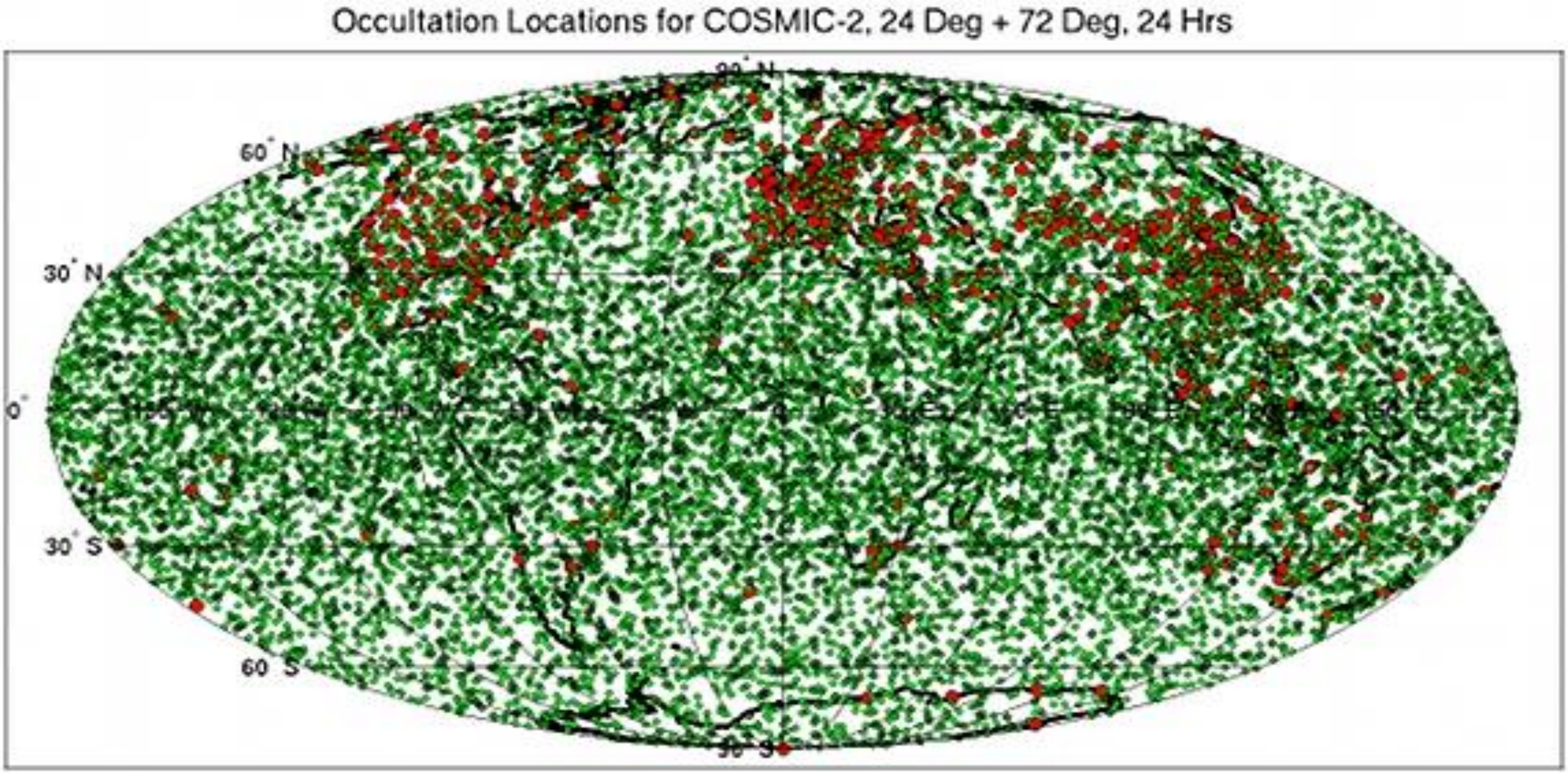
[Courtesy Healy et al., ECMWF]

- RO typically in top five contributing systems

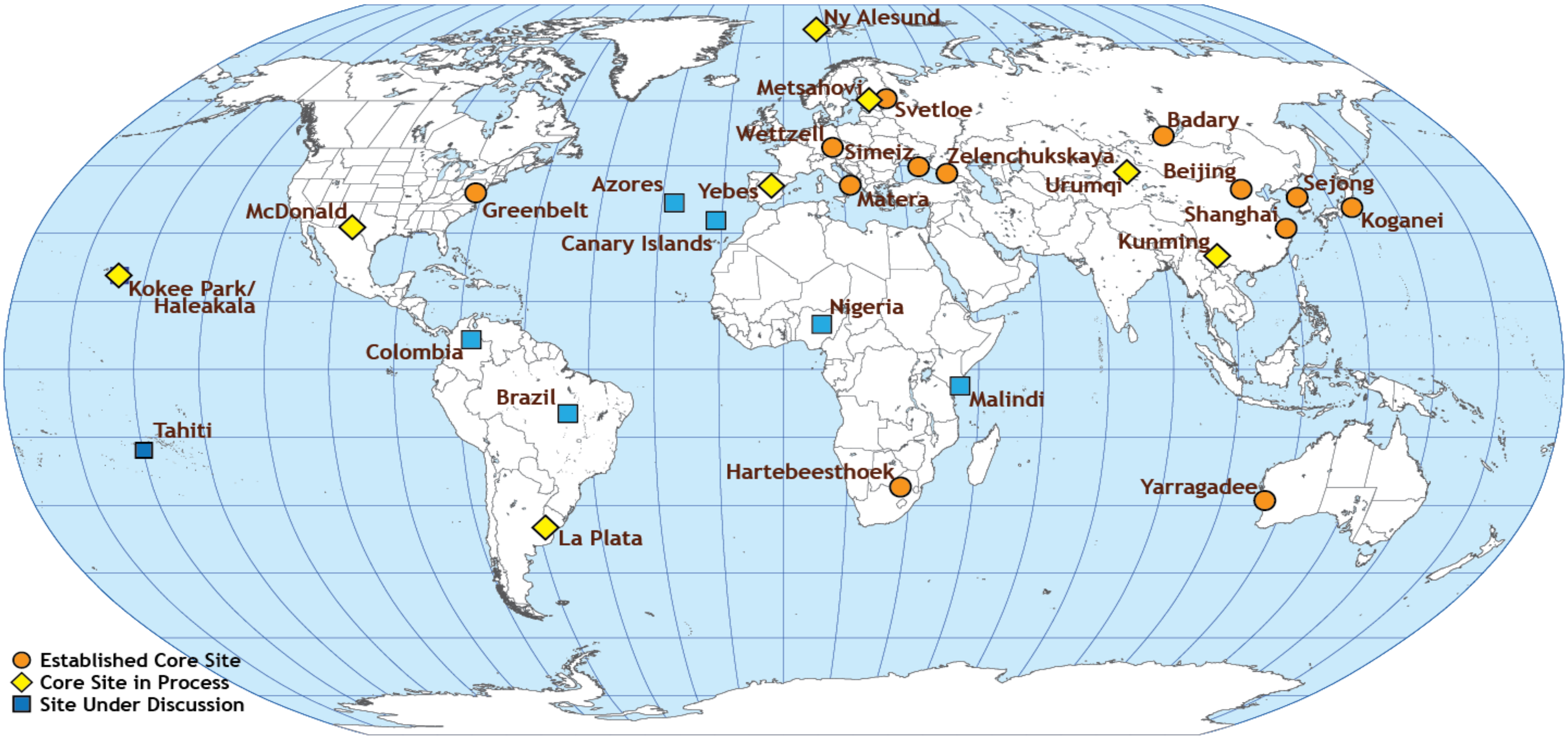
23

COSMIC 2: 12,000 Daily Global GPS and GLONASS Occultations

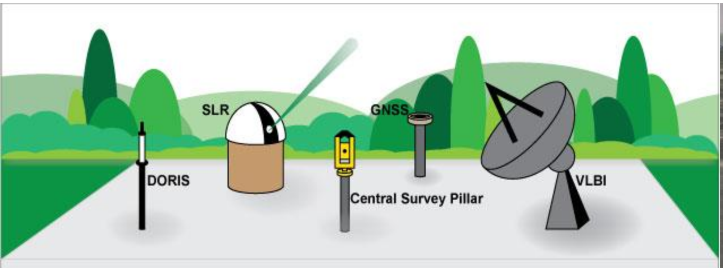
- Red Dots are Radiosonde launches
- Multi-GNSS Occultation density could quadruple after 2020



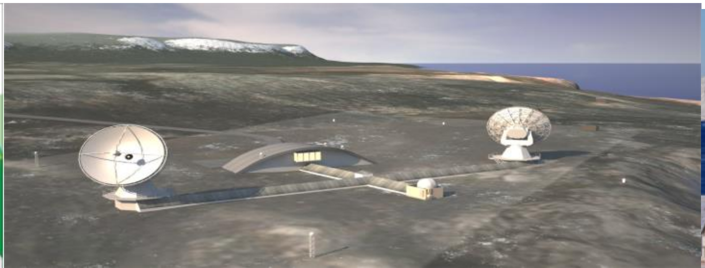
The GGOS 2020: Ground Co-location to remove positioning biases



The GGOS Core Station Concept

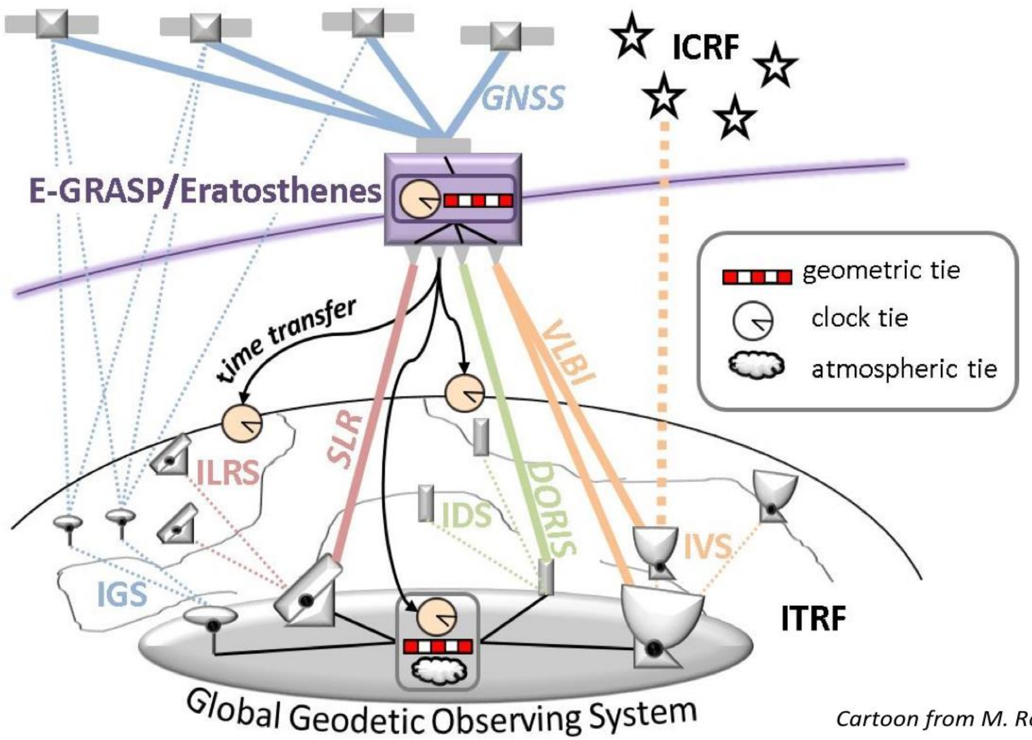


The Ny Alesund Geodetic Observatory



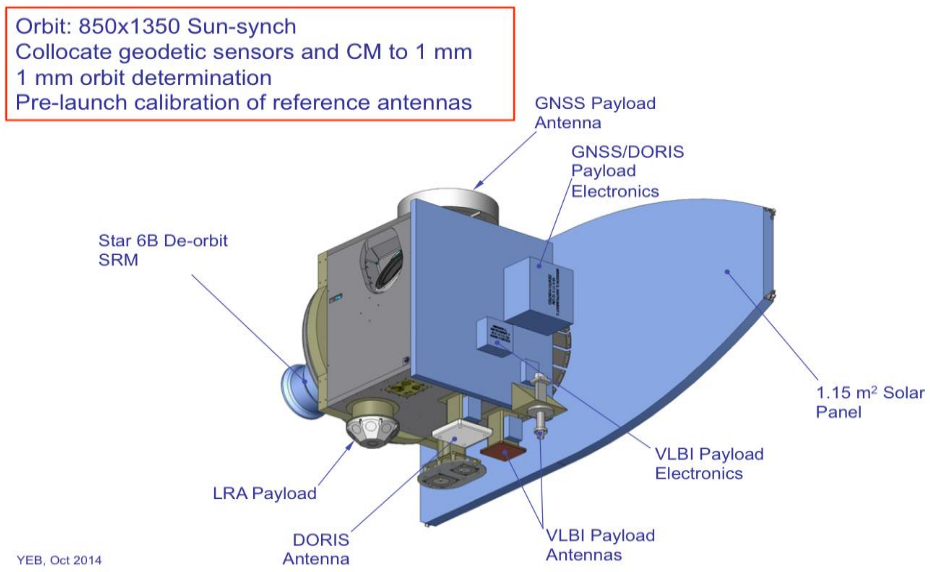
- Inter-technique biases and drifts are obstacles to achieving the required TRF stability

- GRASP/e-GRASP satellite concepts offer a common target for all techniques to identify technique-specific systematic errors



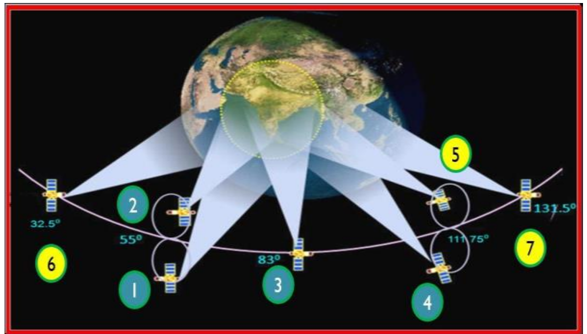
Cartoon from M. Rothacher, ETH

GRASP

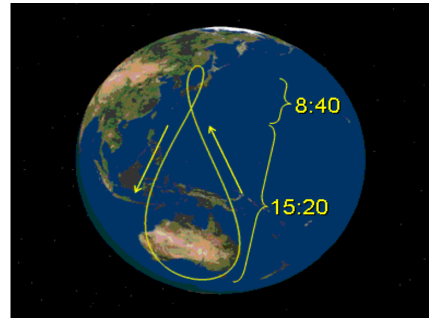


Coming in 2022…
115-MEO, 9-GEO,13-GSO GNSS Satellites

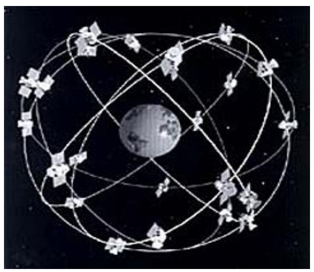
NAVIC
(4-GSO,3-GEO)

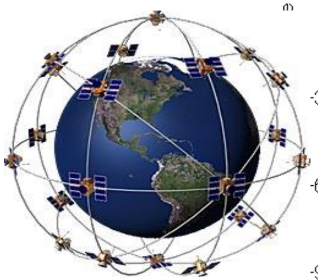


QZSS
(6-GSO, 1-GEO)

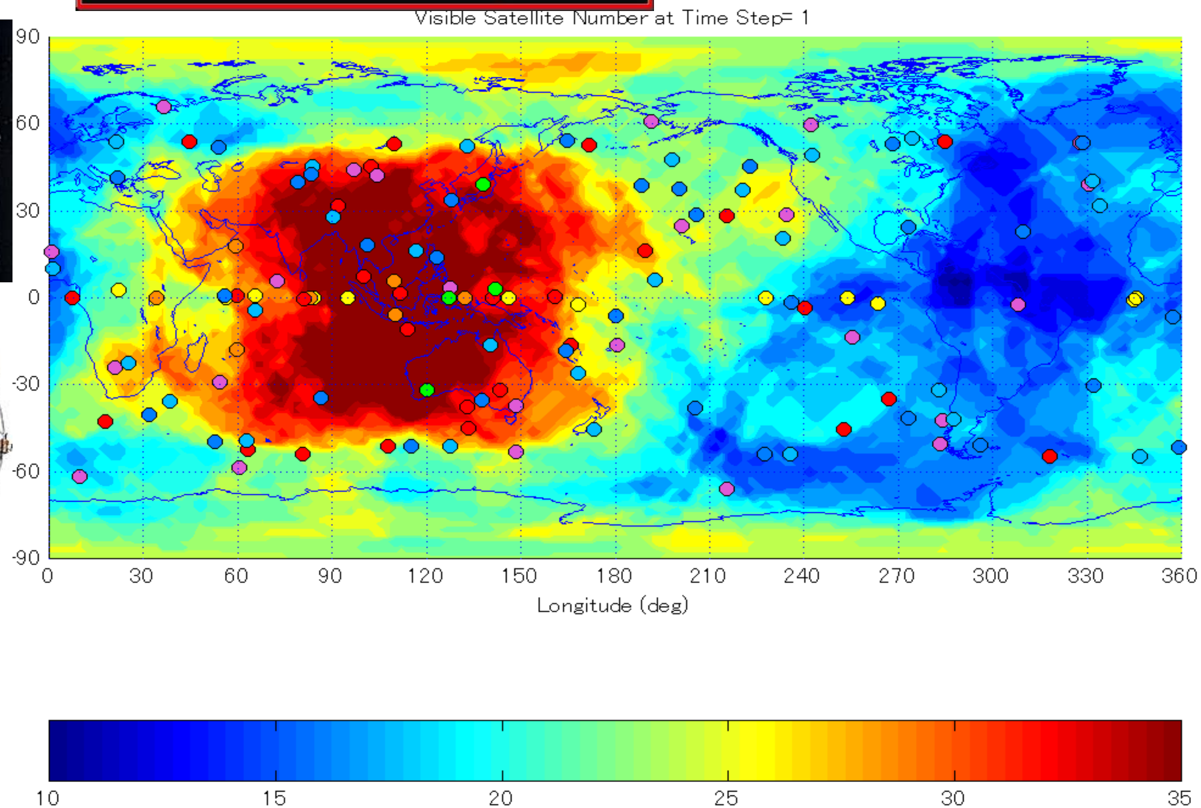


Galileo
(30 MEO)

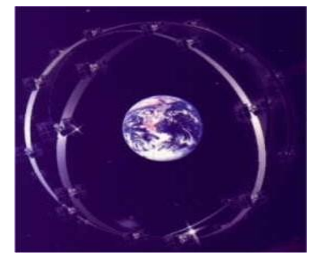




GPS
(31 MEO)



GLONASS
(24 MEO)



Beidou
(3-GSO,
5 GEO,
30 MEO)

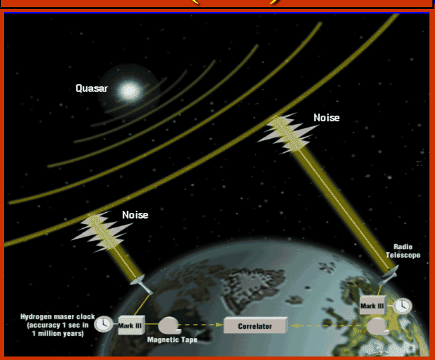
The GGOS 2020 Global Geodetic Observing System

Dynamic Terrestrial Reference Frame
mm accuracy

International Earth Rotation Service
(IERS)

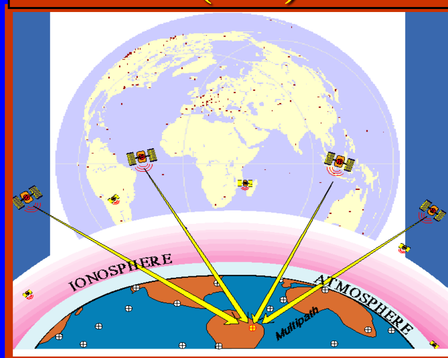
Real Time Geodetic Observations
GNSS Orbits and Clocks, e-VGOS, Khz Laser Ranging, Multi-GNSS Monitoring
Mass Transport Obs.

Very Long Baseline Interferometry (IVS)

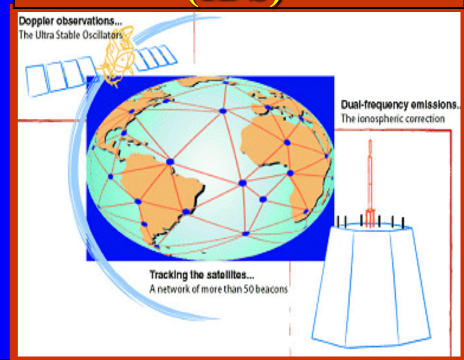


Satellite Laser Ranging (ILRS)

Global Navigation Satellite Systems (IGS)

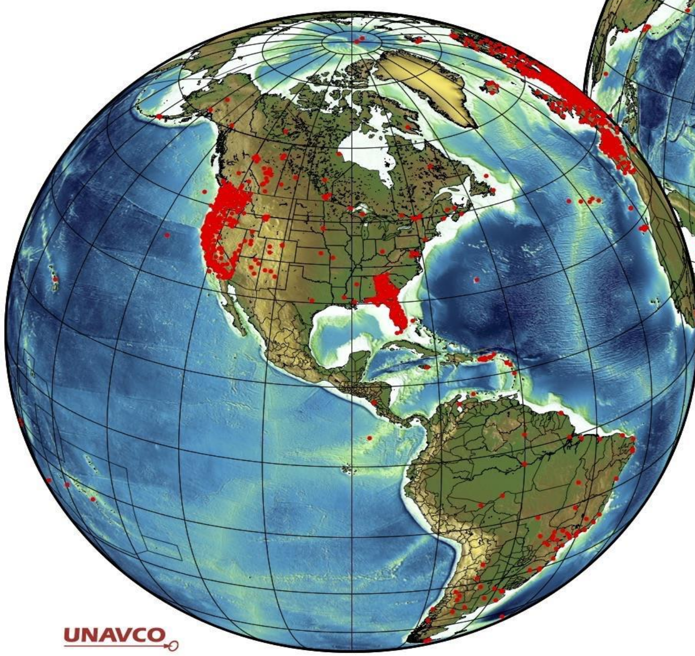


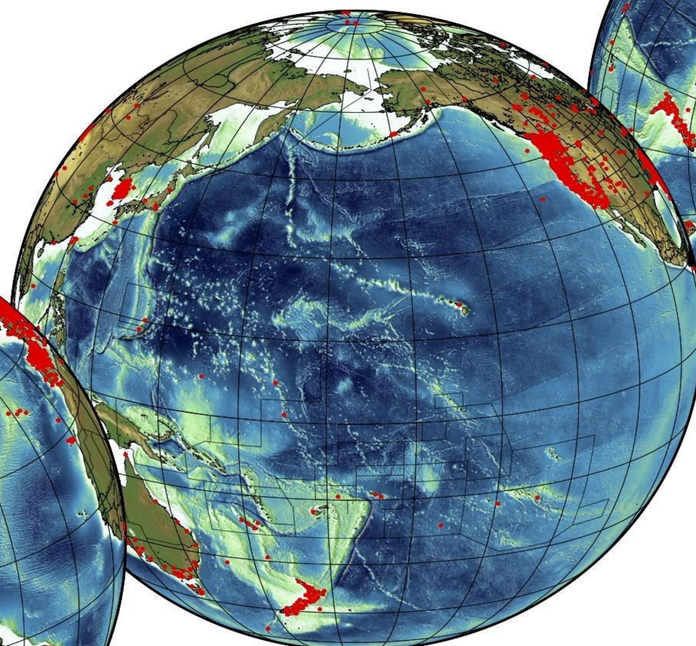
Doppler Orbit Determination and Radiopositioning Integrated on Satellite (IDS)

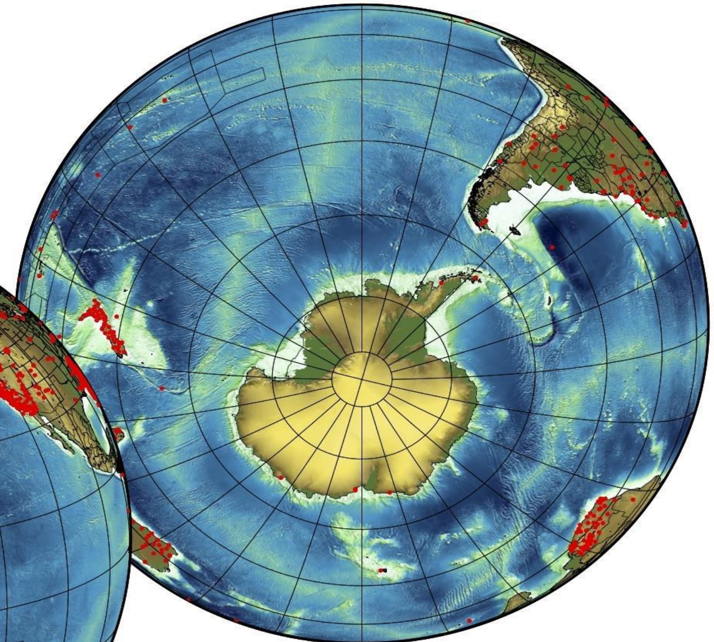


Real Time GNSS will bring significant new
Benefits to society and science e.g.

- Exploration,
- Weather Prediction.
- Geohazards Mitigation,
- Commerce etc





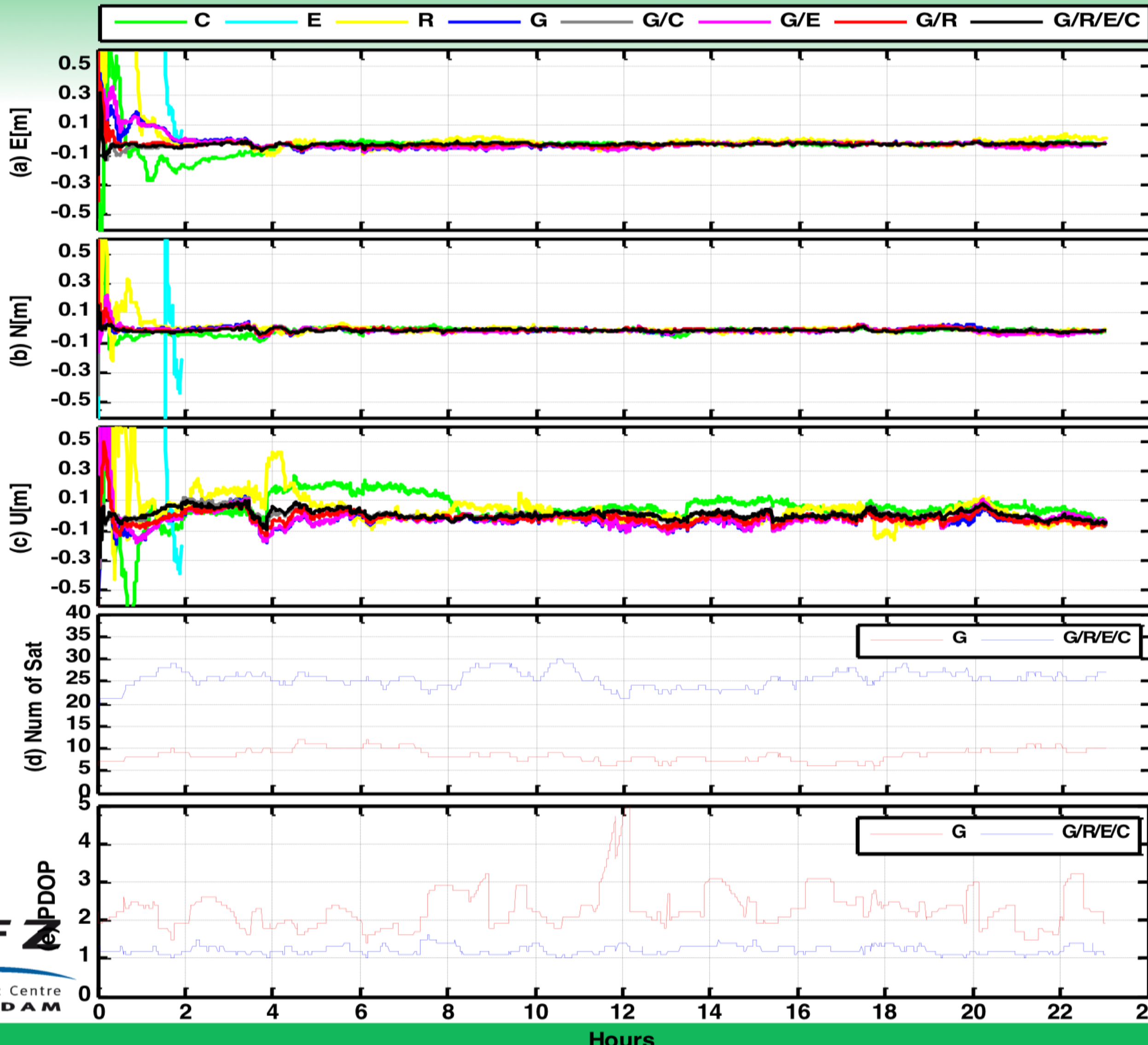


Political, Commercial and Communications limitations are
Primary Causes for Restricted Access

uced by UNAVCO/Mencin 2015

Multi-GNSS Real Time operations may present challenges to solution accuracy

4 Multi-GNSS real-time PPP



Precision Real Time GNSS relies upon differential corrections either through Real Time Kinematic (RTK) Corrections or via Precise Point Positioning (PPP). PPP can provide global solutions but convergence time is a challenge for rapid access.

Multi-GNSS presents new challenges but may generating improve convergence time and stability.

These are results or kinematic positioning of one receiver.

Li et al., IGS2016

GFZ Helmholtz Centre POTSDAM

Recent works indicate overall improvement with Mult-GNSS solutions

4 Multi-GNSS real-time PPP

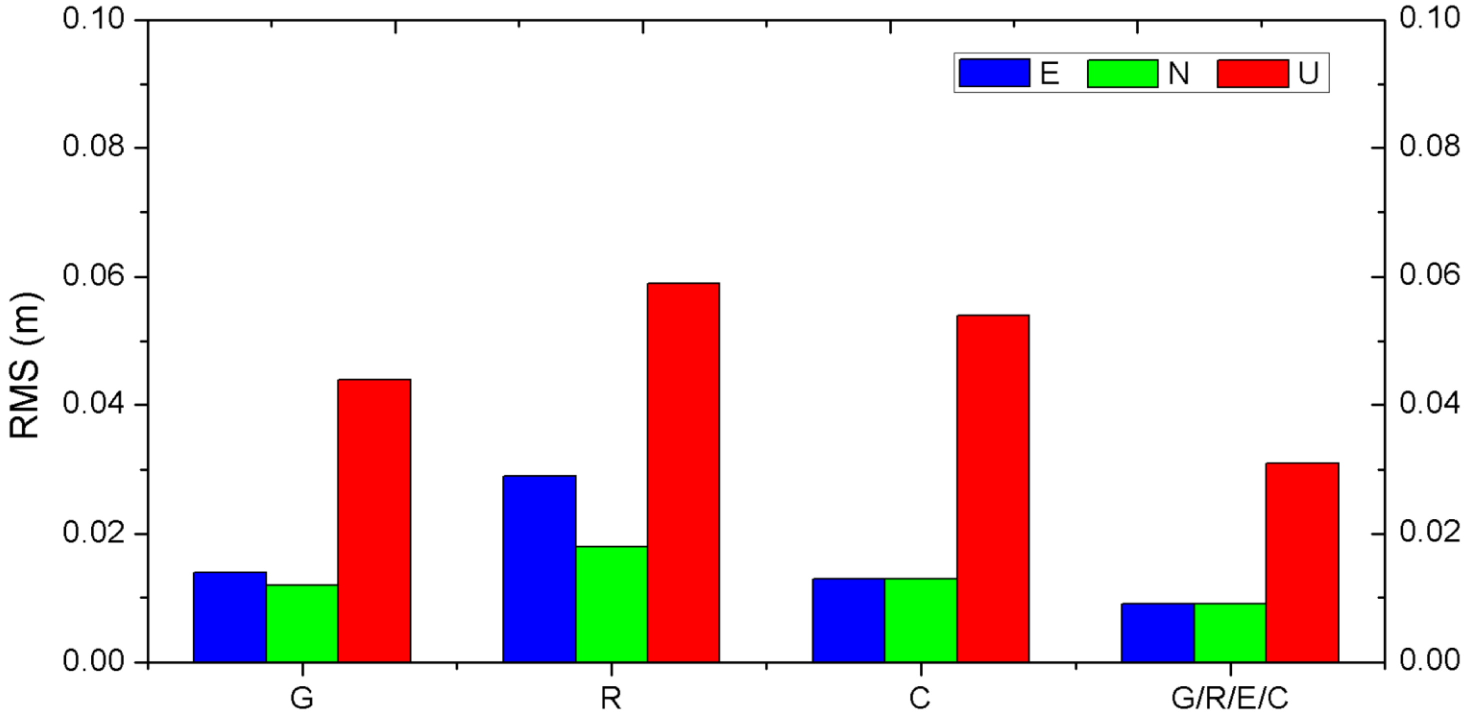


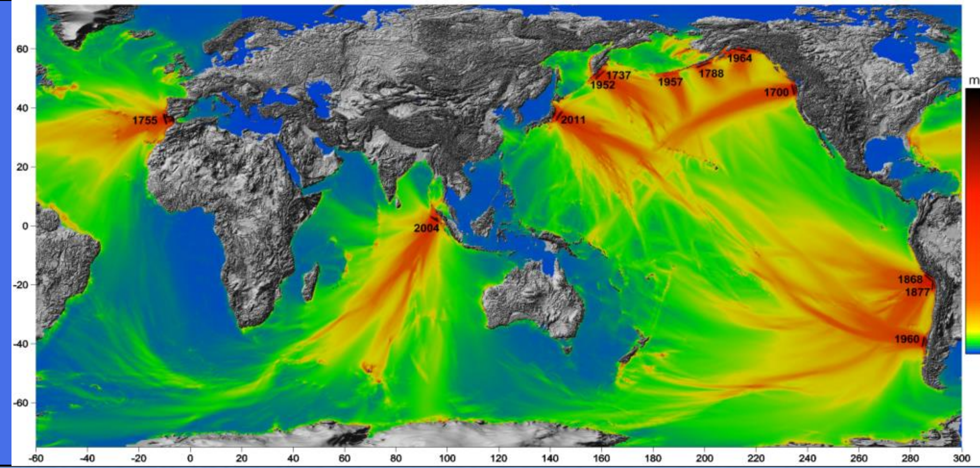
Figure 13. The averaged RMS values of all the stations for kinematic PPP solutions in north, east and up components.

Li et al., IGS2016

Earthquake and Tsunami Early Warning

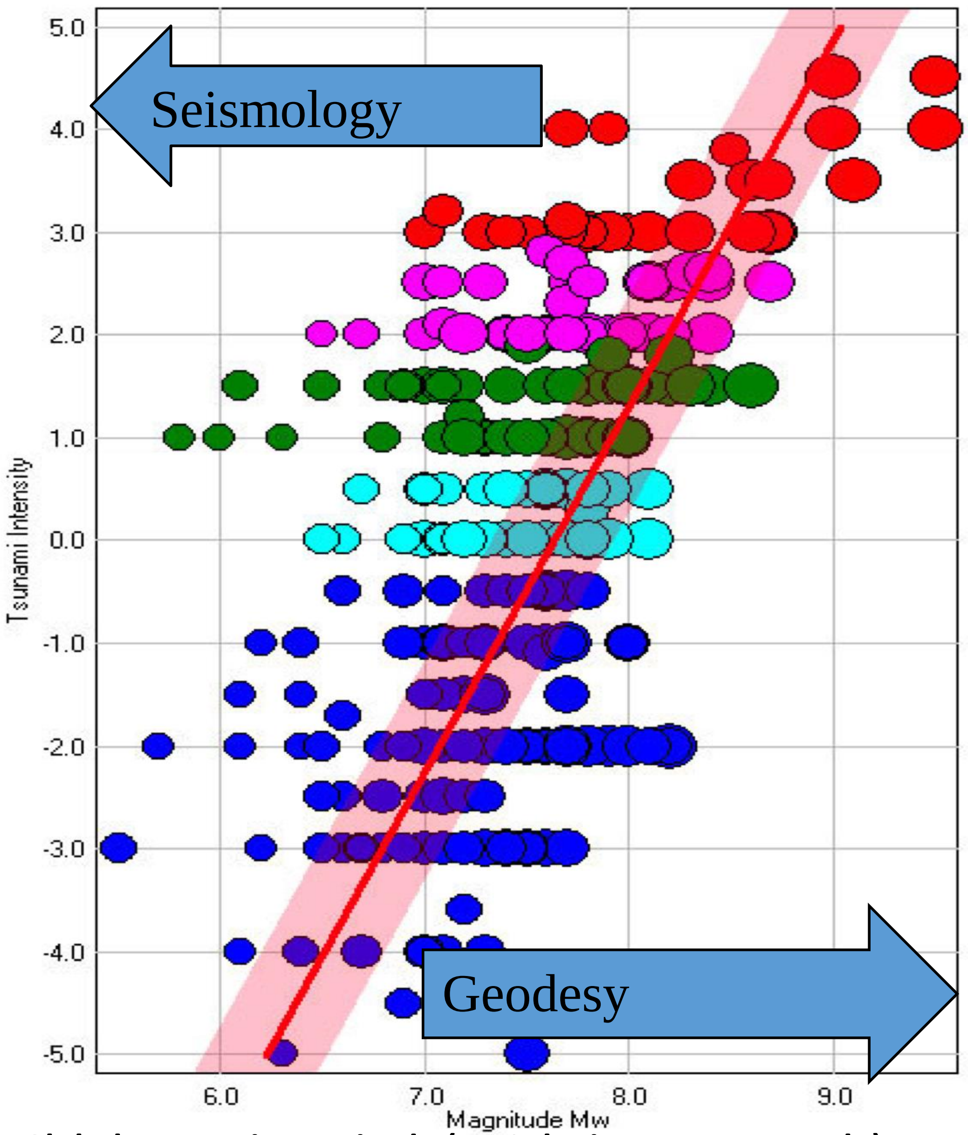
Most tsunami deaths occur
within first hour of an earthquake

Early Warning requires
accuracy and speed (~ 5 min)



Phuket Island, Thailand
December 26, 2004

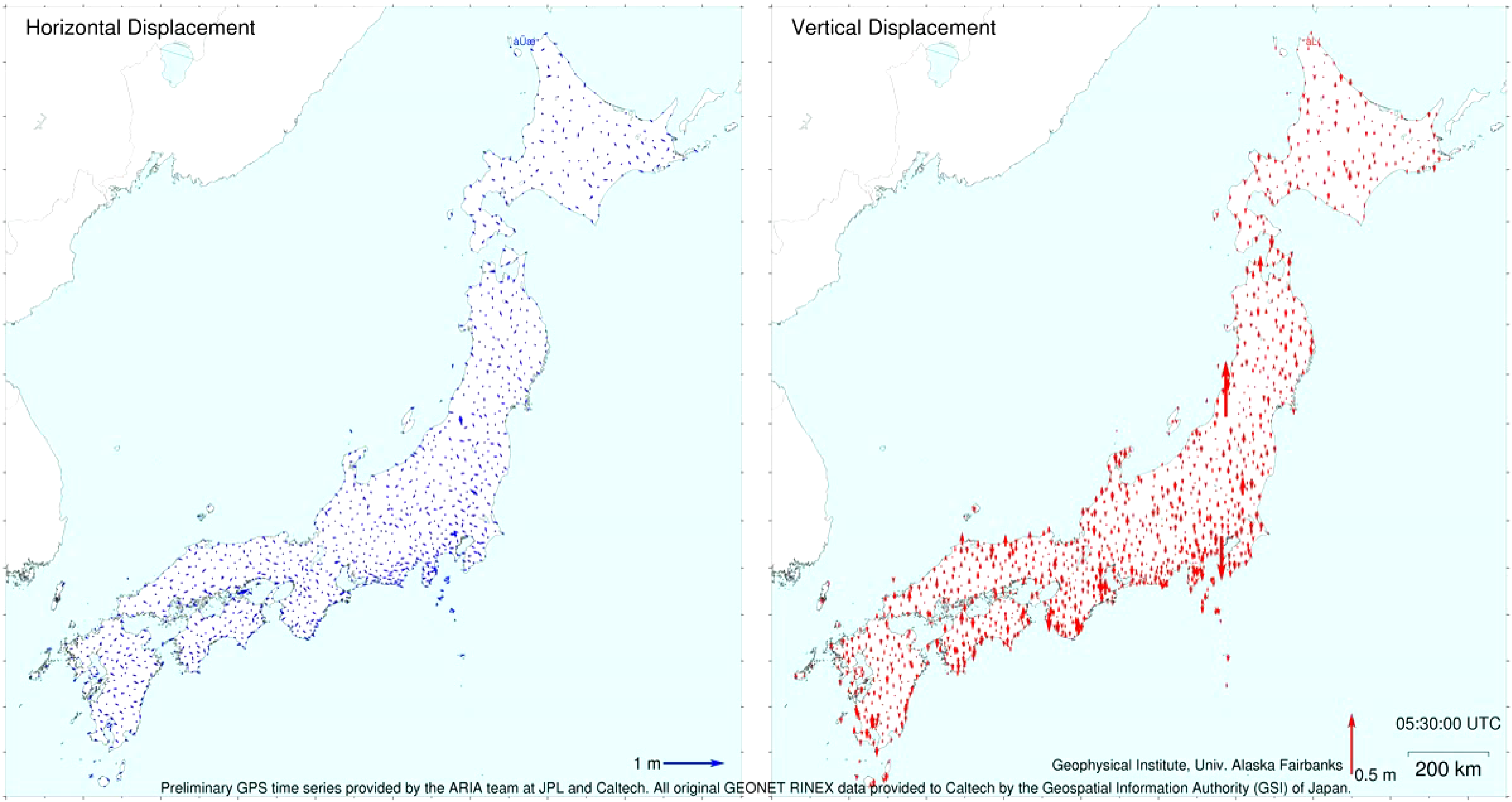
Seismo-Geodesy provides accurate, early warning of Earthquake Magnitude



Global Tsunami Magnitude (on Soloviev-Imamura scale) vs Earthquake Moment Magnitude since 1900 (from-Gusiakov, 2015)

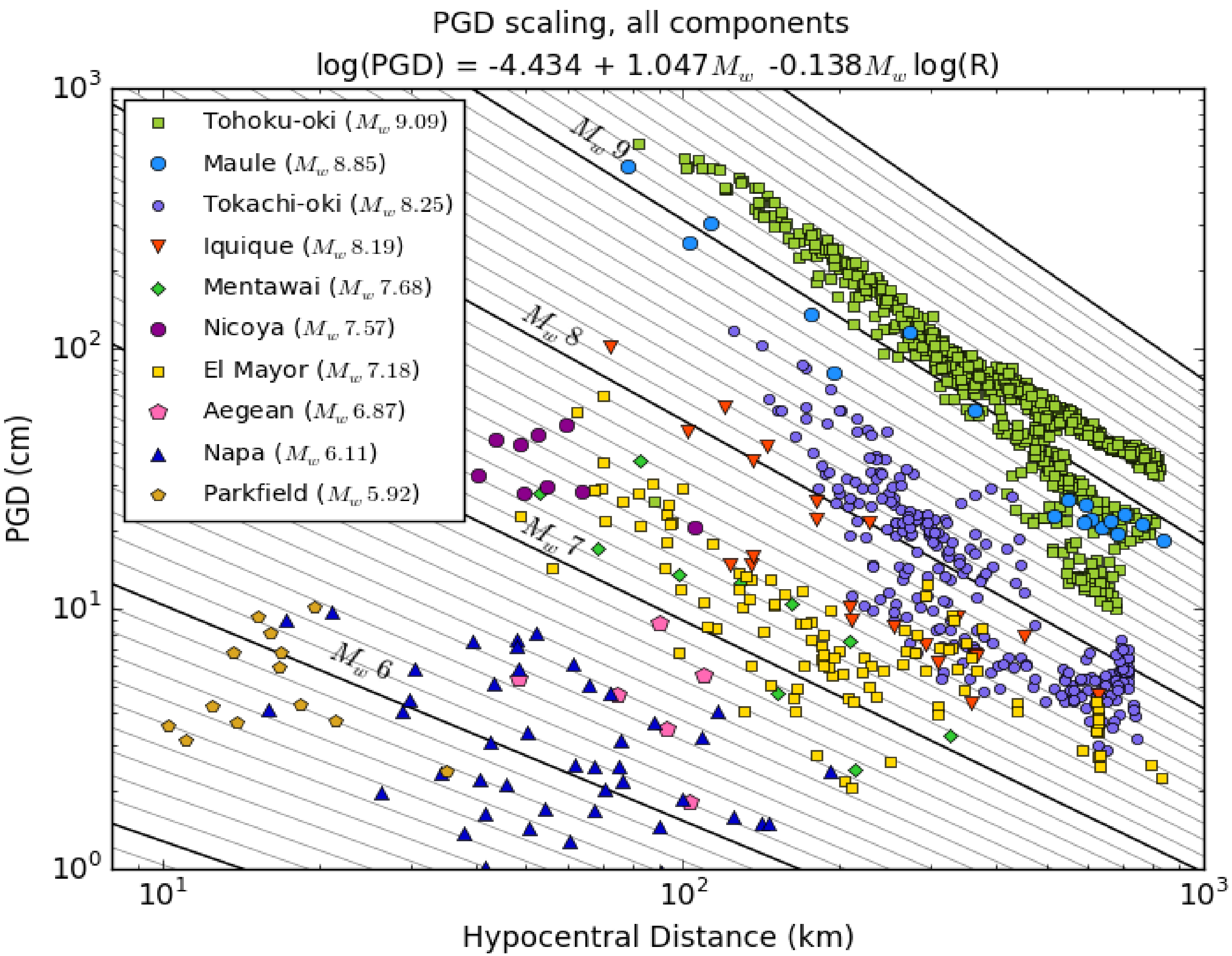
- **Near Field: Accurate inversions for earthquake moment magnitude, displacement, and predictive tsunami models within 5 minutes of major earthquakes.**
- **Far Field: GNSS provides validation and tracking of ionospheric gravity waves coupled to propagating tsunamis.**
- **Significant Infrastructure Development:**
  - **GNSS constellations,**
  - **Real time networks**
  - **Analysis capabilities**

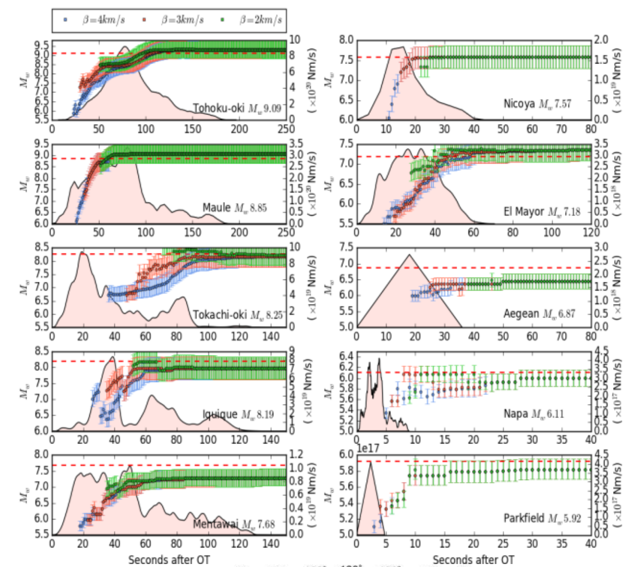
GSI's GEONET GPS Network Demonstrated the Capture of both Static and Dynamic Deformation

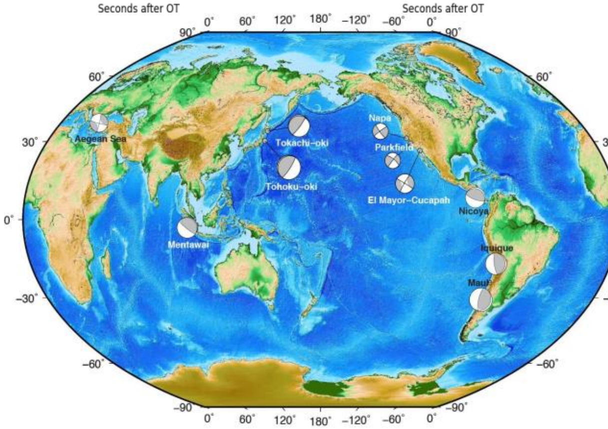


Scaling GNSS Peak Ground Displacement (PGD) yields rapid accurate earthquake magnitude

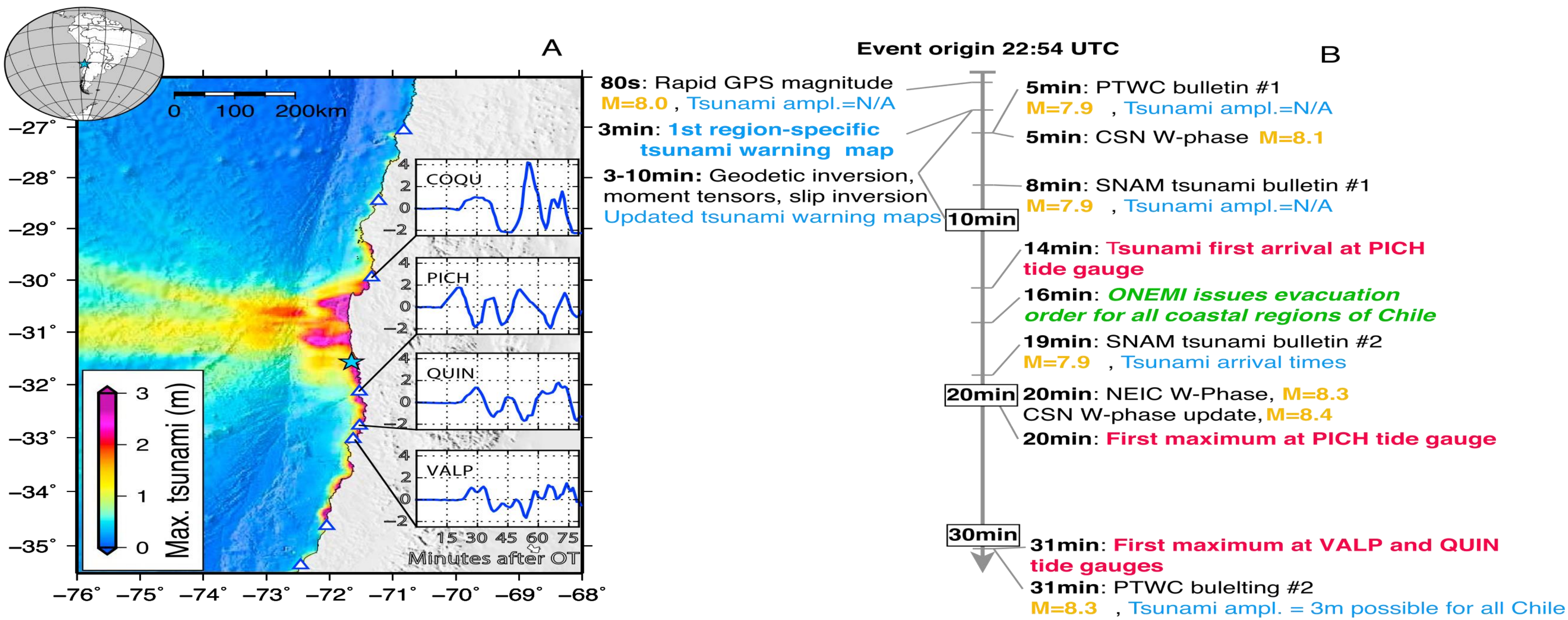
-GNSS directly measures ground displacement without clipping
-Magnitude is determined by using regression parameters and range (Melgar et al.,2015)





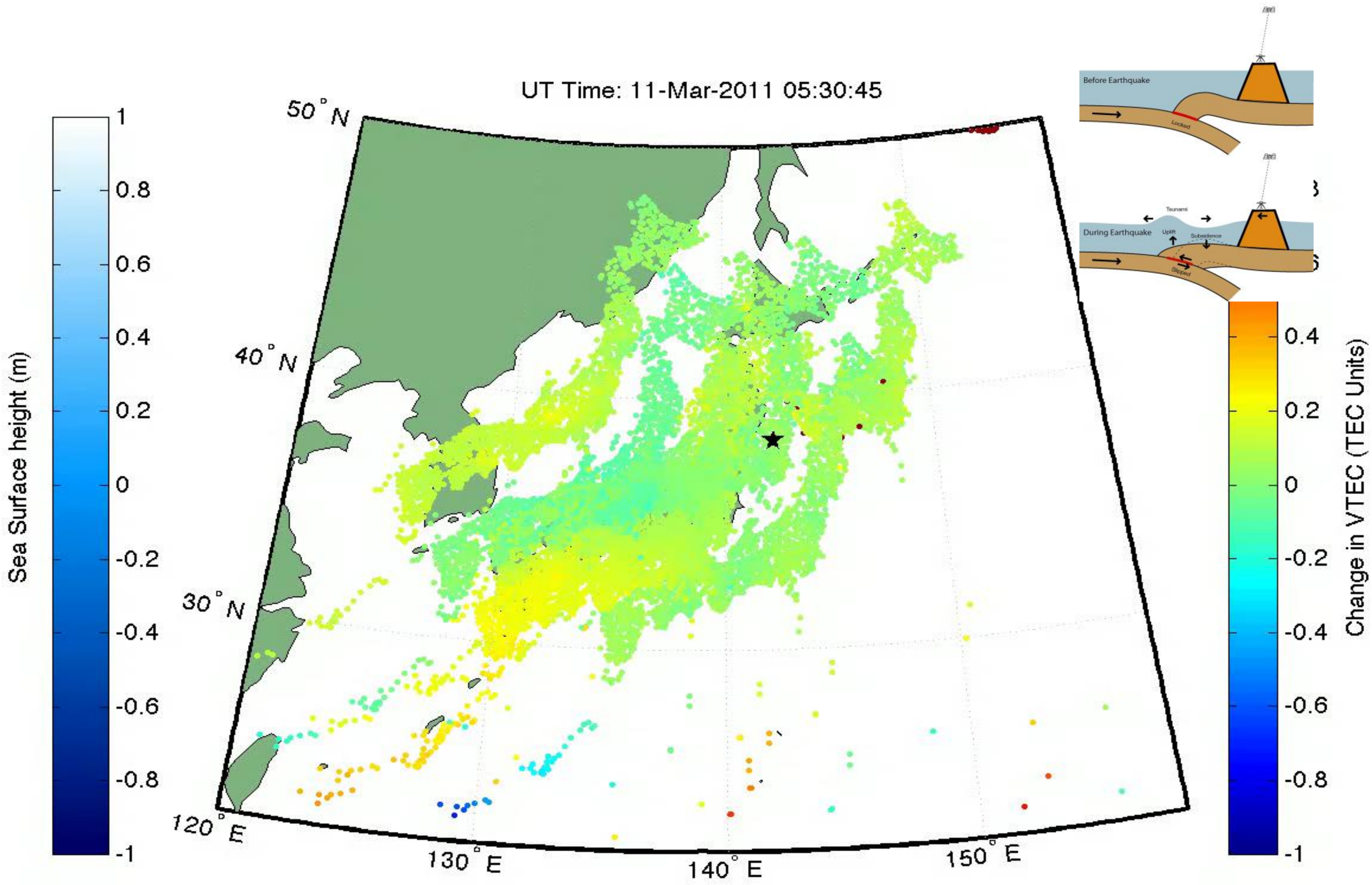


GNSS surface displacement used for earthquake and tsunami estimate in less than 5 minutes



From: Melgar, D., R. M. Allen, S. Riquelme, J. Geng, F. Bravo, J. Carlos Baez, H. Parra, S. Barrientos, P. Fang, Y. Bock, M. Bevis, D. J. Caccamise, C. Vigny, M. Moreno and R. Smalley Jr., Local Tsunami Warnings: Perspectives from Recent Large Events, *Geophys. Res. Lett.*, 2016.

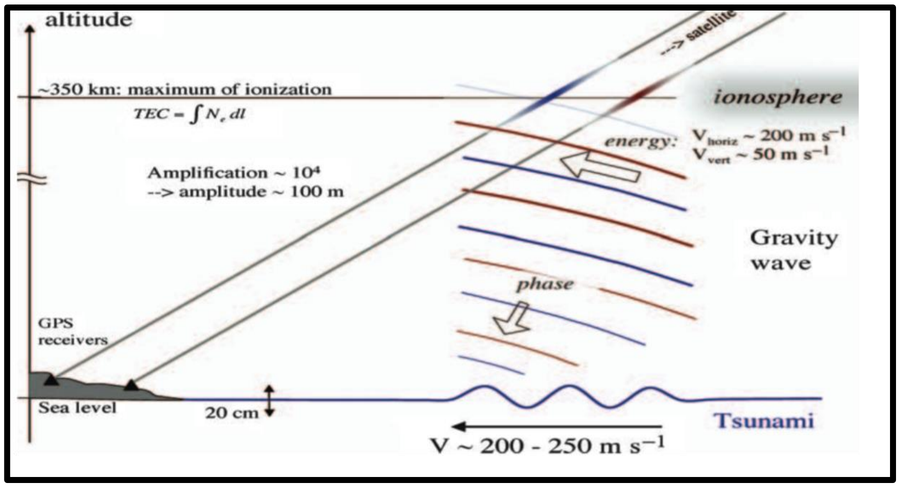
GSI's GPS Network GEONET Provided the first Images of Tsunami Generation and Propagation



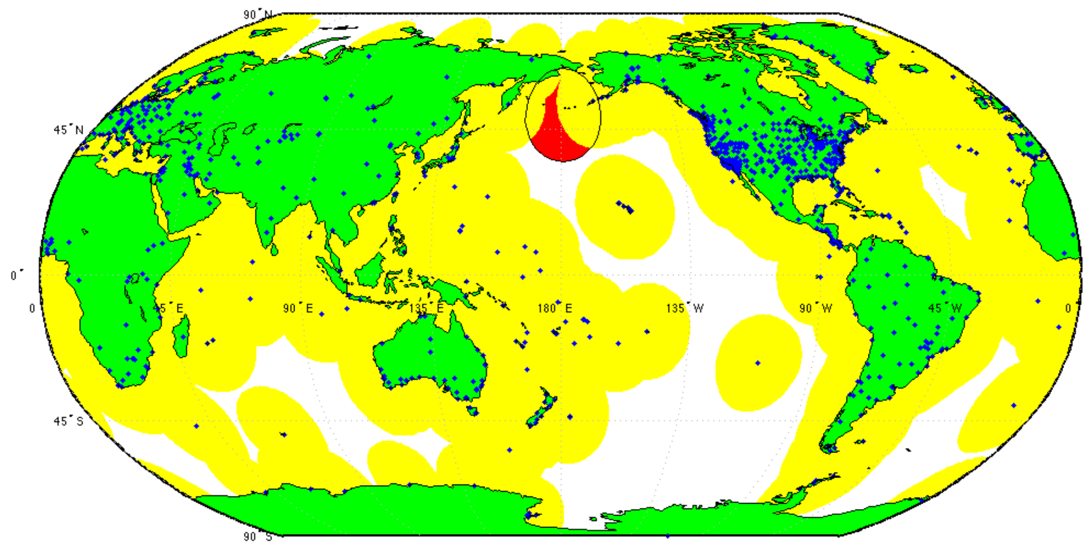
Ionospheric Response to Mw9.0 Tohoku Earthquake and Tsunami in Japan on March 11, 2011, A.Komjathy, D.A.Galvan, M.P Hickey, P.Stephens, Mark Butala, and A.Mannucci, (http://visibleearth.nasa.gov/view.php?id=77377)

GNSS Over the Horizon Tsunami Tracking with Existing Network

Yellow zones indicate region of ionospheric piercing point detection from existing GNSS receiver network. Assumes 10 degree elevation and the Ionospheric shell at 350 km yields about 1 hr advance tsunami detection

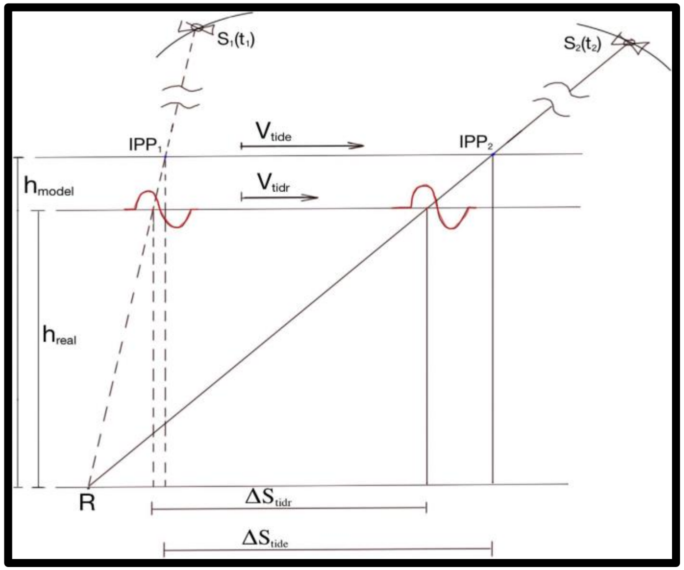


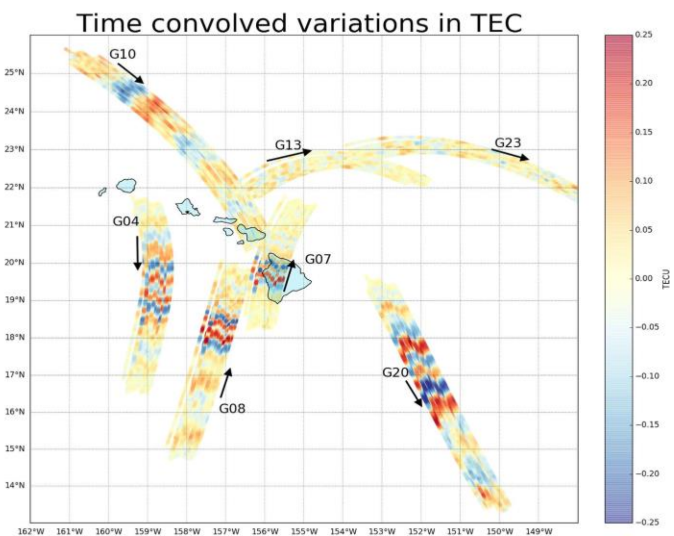
Physics of GNSS imaged Ionospheric gravity waves

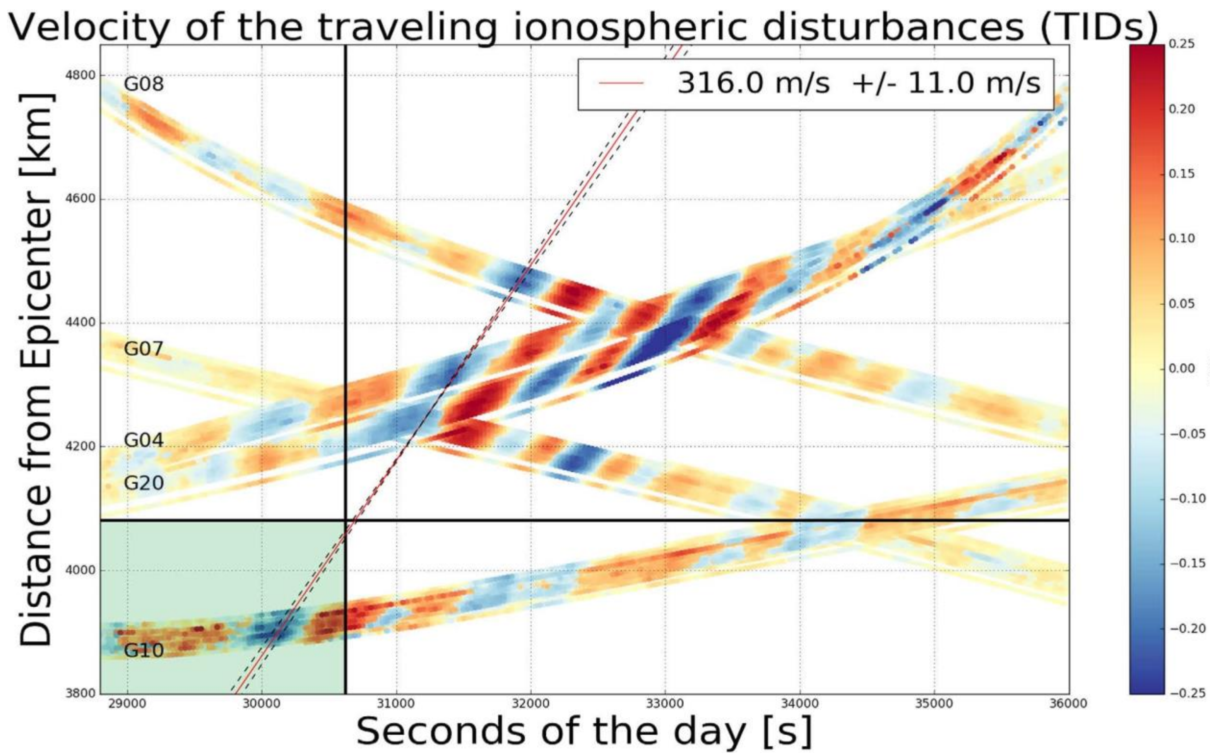


Red zone is only circum-Pacific gap in coverage assuming all stations are upgraded to real time operation.

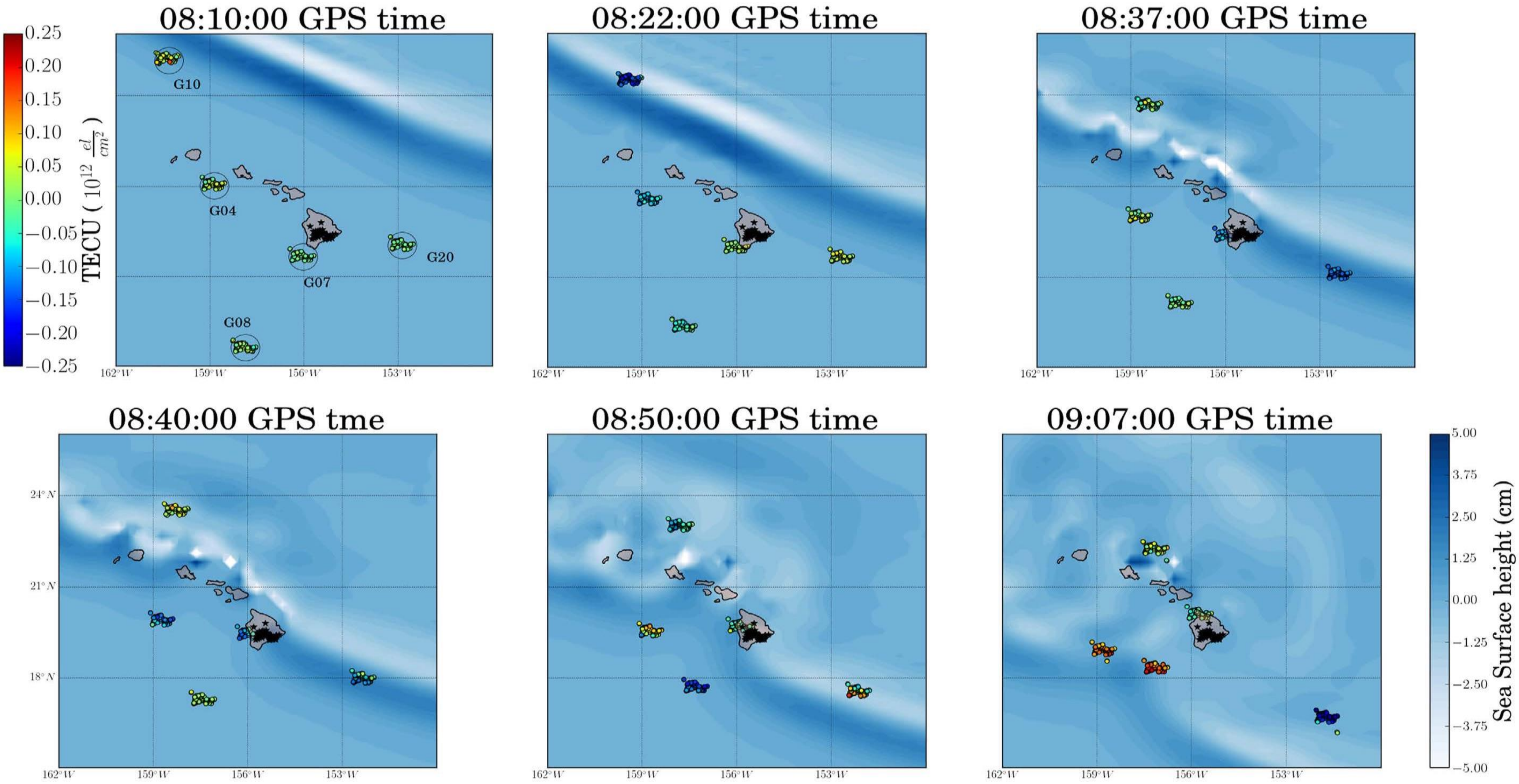
Real Time Detection of Tsunami Ionospheric Disturbances *(Savastano et al., 2017)*



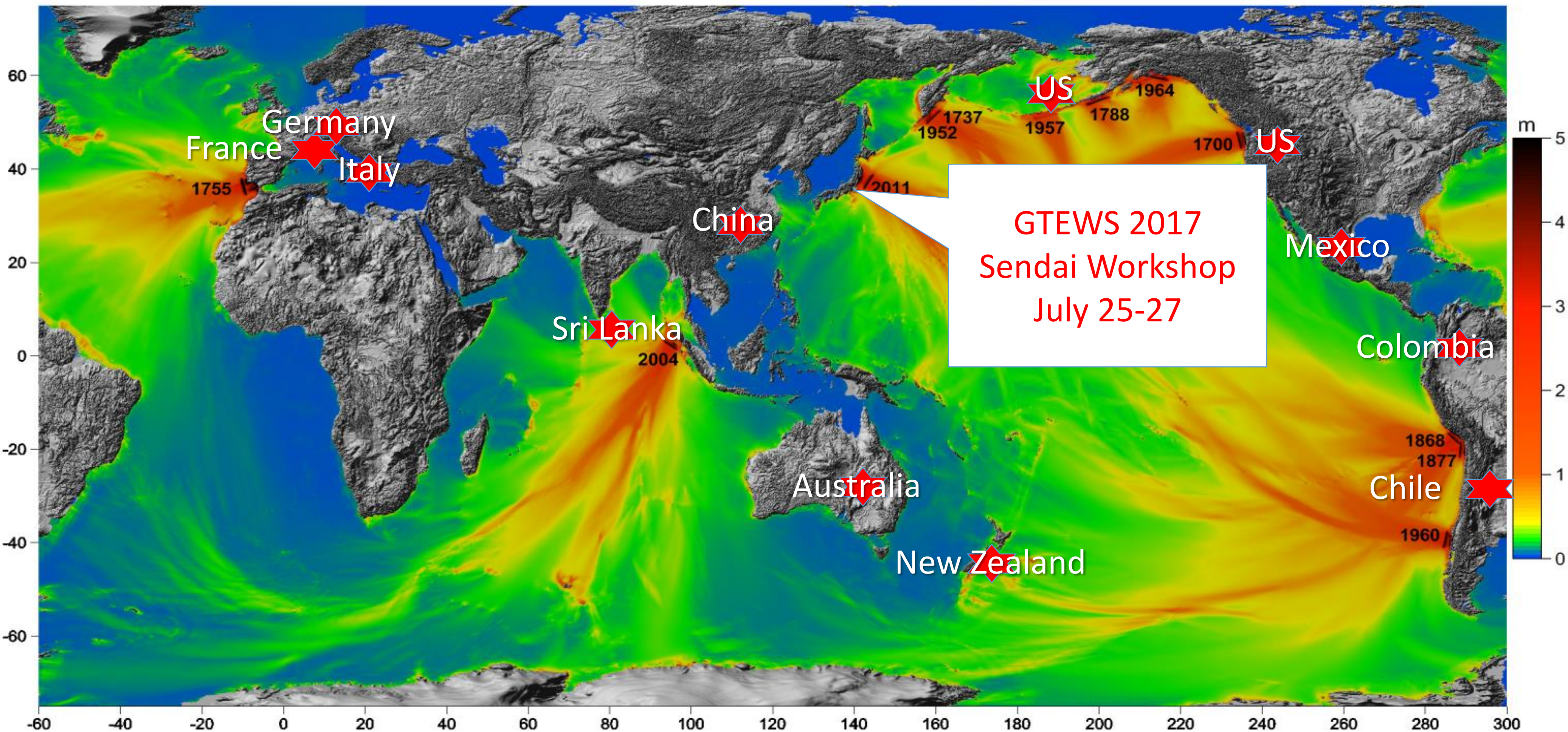




Hindcast detection of a 5 cm tsunami approaching the Hawaiian Islands from the Northeast Pacific



GTEWS 2017 Workshop on GNSS Tsunami Early Warning Systems



11 Nations
16 member Agencies and Institutions

Conclusion: Promise vs. Challenges

The Promise: Emerging real time multi-GNSS capability will improve the effectiveness and efficiency of Environmental and Geohazards Monitoring.

Challenge of Policy : Increase access and data sharing to real time GNSS network data.

Challenge of Habit : Integration of Geodesy within Environmental and Geohazards Montoring Programs.

Thank you!!!

Join the Global Geodetic Observing System of the IAG in strengthening the Global Tsunami Warning Systems through International Cooperation

Thank –you!!

GGOS Working Group on GNSS Augmentation for Tsunami Warning (GATEW)

Green cells signify GTEWS2017 registration as of May 1, 2017

Country	Organization	Resources	Contact	Email
Australia	GeoScience Australia	Large National Real Time GNSS Network	John Dawson	John.Dawson@ga.gov.au
Chile	U.Chile, Department of Geophysics, CSN	Large National Real time Geodetic and Seismic Network	Sergio Barrientos, Sebastián Riquelme, Juan Baez	sbarrien@dgf.uchile.cl, sebastian@dgf.uchile.cl,jcbaez@csn.uchile.cl
China	GNSS Research Center, Wuhan University	First Real Time Asian Analysis Center	Jianghui Geng	jgeng@whu.edu.cn
Colombia	Geological Survey Colombia	Large Real Time GNSS Network, Regional Data Sharing with Brazil, Peru, Panama, Venezuela, COCONet Data Center	Hector Mora	hmora@sgc.gov.co
France	Institut de Physique du Globe de Paris	Strong research in tsunami coupled ionospheric waves and tracking	Giovanni Occhipinti	ninto.a.paris@gmail.com
Germany	GeoForschung Zentrum, Department Geoservices	Strong research and development of GNSS Early Warning including Indonesia and Oman projects	Harald Shuh, Jörn Lauterjung	schuh@gfz-potsdam.de, lau@gfz-potsdam.de
Italy	University of Rome Geodesy and Geomatics	Initiating research in GNSS Tsunami Warning	Mattia Crespi, Augusto Mazzoni	mattia.crespi@uniroma1.it , augusto.mazzoni@uniroma1.it
Mexico	Instituto de Geofisica, UNAM	Large National GNSS network and analysis system, COCONet Data Center	Enrique Cabral	ecabral@geofisica.unam.mx
New Zealand	GNS Science	Large National Network	Elisabetta D'Anastasion	E.DAnastasio@gns.cri.nz
New Zealand	Land Information New Zealand	Large National Network	Dion Hansen	DHansen@linz.govt.nz
Sri Lanka	Survey Department of Sri Lanka	Strong interest in developing Tsunami Early Warning	P. Sangakkara,Mr A. Dissanayeke	dsggeode7c@survey.gov.lk,addsgc@survey.gov.lk
USA	Georgia Tech	Significant focus on subduction zone activity and the generation of tsunamis	Andrew V. Newman	anewman@gatech.edu
USA	Jet Propulsion Laboratory	Real time expertise, Ionospheric mapping, global and operations, earthquake and tsunami warning	Attila Komjathy, Tony Yuhe Song	attila.komjathy@jpl.nasa.gov, Tony.Song@jpl.nasa.gov
USA	UNAVCO	Global GNSS networks, real time data systems, Global GNSS support	Linda Rowan	rowan@unavco.org
USA	READI Working Group	NASA-NOAA working group developing GNSS Based Tsunami Warning	Yehuda Bock, Timothy Melbourne	ybock@ucsd.edu, tim@Geology.cwu.edu
USA	NASA	NASA Solid Earth Science. Provides funding from GNSS Tsunami Warning development. Cooperating with NOAA in this effort.	Gerald Bawden	gerald.w.bawden@nasa.gov